Update on the Algorithmic Basis and Predicted Performance of Selected VIIRS Environmental Data Records

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Abstract – The Visible/Infrared Imager/Radiometer Suite (VIIRS) will fly later this decade on the NPOESS Preparatory Project (NPP) and then on the National Polar-Orbiting Operational Satellite System (NPOESS). It will produce 21 different types of Environmental Data Records (EDR's) as well as Intermediate Products (IP's) of global atmospheric and surface geophysical products. Many of these EDR's and IP's are similar in nature to those currently produced by NASA's EOS project from data collected by the Moderate Resolution Imaging Spectrometer (MODIS). Together, the data products from MODIS and VIIRS will provide a long term record of environmental parameters.

The science code to retrieve VIIRS EDR's is largely completed and is being converted into operational code. Algorithm refinements continue in selected areas based upon performance assessments using simulated and proxy data. Most of the VIIRS algorithms follow closely those developed from heritage sensors, e.g. MODIS and SeaWiFS (Sea-Viewing Wide Field Sensor). However, some differences exist due to differences in sensor design (such as the unique VIIRS requirement for near-constant spatial resolution), the absence of heritage products (such as a cloud base height and ice age products), or the demonstrated inability of heritage algorithms to meet the stringent VIIRS system requirements (such as land, water, and ice surface albedos). In the latter cases, Northrop Grumman, US Government, and NASA NPP scientists have worked together to improve overall algorithm performance to meet the stringent NPOESS system specifications for EDR product quality.

This presentation will discuss the algorithmic basis and predicted performance of selected EDR's. Algorithms to be discussed are those used to create the VIIRS Cloud Mask (VCM), sea surface temperature, and land surface temperature products.

I. INTRODUCTION

VIIRS will collect data in 22 spectral bands at two spatial resolutions: five imagery bands at 375 m while 16 radiometric bands have a resolution of 750 m at nadir. Pixel growth is constrained to no more than 2:1 grown in both data types across the 3000 km data swath. VIIRS also has a constant cross-track 750 m resolution day-night-band (DNB) to collect visible data under low-light, lunar conditions. Some bands are dual-gain to support the retrieval of both ocean and atmospheric products. More detail on VIIRS can be obtained from Murphy et al. (2006) and detailed comparisons between VIIRS bands and heritage instruments are available in Tables 5.1 and 5.2 by Hutchison and Cracknell (2005). Requirements for VIIRS EDR's are documented in the Integrated Operational Requirements Document (IORD) with assistance from both the civilian and U.S. military user communities.

II. VIIRS CLOUD MASK

Stringent requirements have been levied upon the VCM analyses and are documented in the NPOESS System Specification, the document that defines acceptable performance for the total NPOESS system and each sub-system. Cloud detection requirements vary according to cloud optical depth (OD) and solar illumination conditions. For example, during daytime conditions, over the ocean, and outside sun glint regions, the VCM algorithm is required to detect 99% of the pixels that contain clouds that are optically thick (OD > 0.5) and 92% of the more optically thin clouds. Inside regions of sun glint, defined by the reflected sun angle < 36 degrees, the cloud mask must meet nighttime performance requirements of 96% and 90% respectively for these same clouds. No other sensor is known to have such stringent performance requirements for cloud analyses.

The methodology for multi-spectral, automated cloud detection algorithms follows closely that first described in the literature by Saunders and Kriebel (1988) which formed the theoretical basis for APOLLO or AVHRR Processing scheme Over Land, Clouds, and Ocean (Kriebel et al 2003), CLAVR (CLouds from AVHRR by Stowe et al., 1999l), SERCAA (Support of Environmental Requirements for Cloud Analyses and Archive by Gustafson et al., 1994), and the MODIS cloud mask algorithm (Ackerman et al., 1998). However, the VCM most closely follows the processing paths of the MODIS cloud mask algorithm. Detailed information on the

VIIRS cloud mask can be found in Hutchison et al. (2005).

There are differences between the VIIRS and MODIS cloud mask algorithms. There are currently four cloud tests unique to the VCM algorithm, i.e. not used in the corresponding MODIS algorithm. These tests were either created specifically for the VCM (Hutchison and Jackson, 2003) or have demonstrated value from heritage algorithms and were added to resolve specific problems identified at NGST during algorithm verification testing. For example, cloud detection thresholds in the M5 (0.672 μm) Reflectance Test has been modified to vary with NDVI and solar scattering angle (Hutchison, et al., 2006) and further modifications replaced the M5 band with the M1 band when NDVI falls below 0.2.

The VIIRS and MODIS cloud mask algorithms output cloud confidences based upon results of numerous cloud detection tests. Possible cloud confidences are confidently clear, probably clear, probably cloudy, and confidently cloudy. A binary cloud mask is created in the VIIRS algorithm by grouping together both classes of cloudy pixels and separately both classes of clear pixels. An example of VIIRS and MODIS cloud confidences along with an NGST manually-generated binary cloud mask are shown in Panels (c) and (d) of Figure 1 respectively. Panel (a) contains a color composite of the scene while a manually-generated cloud mask is in Panel (b). [Cloud confidences are confidently cloudy (red); confidently clear (dark blue); probably clear (light blue); and probably cloudy (yellow).] In this case, the MODIS cloud mask more closely matches the manually cloud analysis in the sunglint region.

The VCM algorithm also produces a cloud top phase analysis. Initially the approach used was based upon the NASA MODIS algorithm (Menzel et al., 2002). However, a new technique that identifies overlap conditions, i.e. occurrences of ice cloud and water cloud layers in a single VIIRS pixel, has been developed through the NPOESS IPO (Pavolonis and Heidinger, 2004). Assisted by the University of Wisconsin Space Science and Engineering Center (SSEC) and NOAA NESDIS, NGST integrated this logic into the VCM algorithm, which now produces seven cloud phase classes including water, thin cirrus, thick cirrus, mixed phase, and overlap, along with clear, partly cloudy, and not executed. The algorithm has been thoroughly tested, with the aid of the Aerospace Corporation in Omaha, NE and is performing well. Panels (e) and (f) show cloud phase analyses for VIIRS (1-km) and MODIS (5-km) respectively. The accuracy of this new approach for detecting cloud overlap is evident by comparing Panels (e) and (a). (Water clouds have a yellow hue and ice clouds appear bluish in the color composite while turquoise indicates overlap and thicker cirrus.)

The VCM is now expected to meet NPOESS performance requirements under most conditions. However, several challenges remain before it fully satisfies the derived requirements for all of the VIIRS algorithms. Improvements are still needed to differentiate between clouds and heavy aerosols, identify cloud shadows, and detect clouds in the polar night. Possible enhancements have been identified to address two of these issues while improved detection during the polar night might be achieved with data collected by the CrIS sensor.

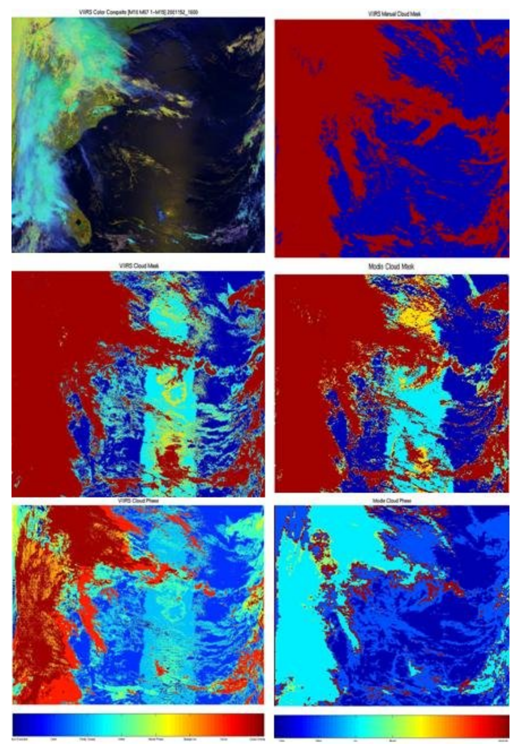

Figure 1. Performance of VIIRS and MODIS cloud mask algorithms on granule MOD2001.152.1600.

III. Sea Surface Temperature

Requirements for the VIIRS SST EDR are also detailed in the NPOESS System Specification and include a skin temperature measurement uncertainty and precision of 0.35 and 0.27 ^{o}K respectively under favorable conditions but 0.50 and 0.45 ^{o}K under unfavorable conditions. (Favorable conditions are defined as within 40 degrees of nadir, surface temperature less than 285 K, negligible cloud cover, and aerosol optical thickness less than 0.2. Unfavorable conditions are defined to be negligible cloud cover and one or more of the following conditions: sensor zenith angles between 40 and 50.3 degrees off nadir, surface temperature greater than 285 K but less than 313 K, aerosol optical thickness greater than 0.2 but less than 1.0). While these requirements appear to be similar to the performance of heritage algorithms used with the AVHRR and MODIS sensors, they are in fact more stringent. The VIIRS requirements must be satisfied for any true value of the parameter within a subset of the overall measurement range, not just the average for the entire measurement range. In practice, measurements will be binned into sets for which the true value of the parameters falls into a narrow range, e.g. 1-2 ^{o}K, that is much smaller than the total measurement range.

Unlike MODIS, the primary VIIRS SST algorithm employs a dual split window (DSW) approach (10.76-, 12.01-, 3.7-, 4.05-μm bands) while a more simple split window algorithm is used in region of possible sun glint (Sikorski et al, 2005). The initial MODIS SST algorithm was described by Brown and Minnet (1999); however, the current (collection IV) MODIS algorithms employ non-linear split window (NLSW) algorithms based upon the (10.8- and 12-μm bands) AVHRR heritage during daytime conditions and a MODIS unique algorithm (3.9- and 4.0- μm bands) for use with nighttime data.

The VIIRS algorithms are stratified by day/night and have four temperature and moisture regimes. The cold/warm stratification is defined by a T_{11} threshold. The warm stratification is divided into three moisture stratifications, dry, average and moist defined by two thresholds based upon the $T_{11} - T_{12}$ feature. On the other hand, the MODIS algorithms are stratified by day/night and have two moisture regimes.

The VIIRS SST algorithms have been tested against global synthetic data and MODIS cal/val datasets. The procedures used to generate synthetic data have been described (Grano et al., 2004) and include top-of-atmosphere radiances predicted for the 1330 NPOESS orbit using the VIIRS sensor model described by detector #1, for the cold orbit, and sensor noise model circa January 2004.

Performance of the VIIRS (skin) SST algorithm with global synthetic data is shown in Figure 2, for favorable [Panels (a)] and unfavorable [Panel (b)] conditions. Similar results are shown for the bulk SST EDR in Figure 3, based upon a global match-up data set provided to NGST by NASA SST Team Members at the University of Miami, Rosenstiel School of Marine and Atmospheric Science. The latter dataset consists of both buoy and MAERI (radiometer) data collocated with MODIS Terra level 1B data, SST retrievals and associated data. The dataset spans four years, 2001 through 2004. Screening of these data was done to remove any cloud contamination and bad in-situ data by comparison to Reynolds SST. APU Performance of the VIIRS algorithm is highly encouraging with both datasets, especially for SST values < 282 K as shown in Panel (a) of Figure 3.

III. LAND SURFACE TEMPERATURE

The VIIRS LST requirements are to retrieved the temperature for the uppermost layer of the land surface (skin) within an accuracy and precision of 2.4 and 0.5 ^{o}K respectively across the range 213 – 343 ^{o}K for pixels classified as confidently clear by the VCM.

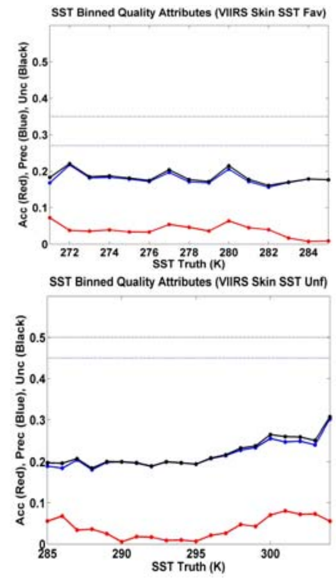

Figure 2. Performance predictions for VIIRS (skin) SST EDR against global synthetic data during favorable conditions.

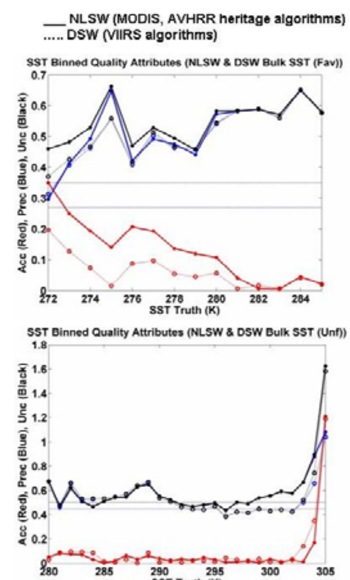

Figure 3. APU for VIIRS Bulk SST and heritage (MODIS & AVHRR) algorithms using MODIS cal/val datasets and VIIRS reporting requirements.

The LST algorithms are similar to the VIIRS SST algorithms since there is the primary approach that employs a dual split-window algorithm (10.76-, 12.01-, 3.7-, 4.05-μm bands) while the secondary approach relies upon a single split-window algorithm. The VIIRS dual split-window day/night LST algorithms establish one equation for each of the 17 International Geosphere Biosphere Program (IGBP) surface types by using four bands (10.8, 12, 3.75, and 4.005 μm) with added solar zenith angle correction during the daytime. The VIIRS Land EDR delivers the 17 IGBP land surface types for the LST retrieval.

One of the difficulties in the development of the LST algorithms is the considerable spectral variation in emissivity in each of the different land surface types. Observations of emissivity spectra show that, in general, emissivity spectra with high values exhibit little variation, while those with lower values exhibit a greater variation. The differences between 10.8 μm and 12 μm bands are small for most of the types, thus making it feasible to use separate sets of coefficients to retrieve LST for each land type (Sikorski and Kealy, 2002).

The VIIRS (skin) LST algorithms have been tested against the same global synthetic data, described in the SST section above, and against MODIS proxy data. Expected performance of the LST based upon comparisons with the MODIS LST product are shown in Figure 3 for a representative sample of the 17 IGBP surface types.

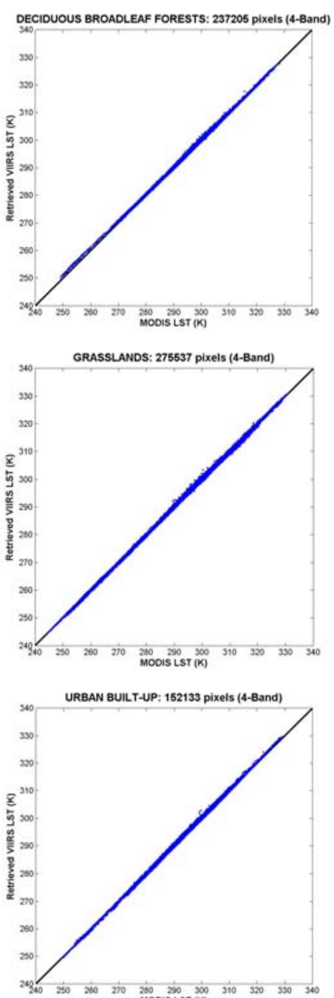

Figure 3. Performance predictions for the VIIRS LST EDR against MODIS proxy data for several IGBP surface types in daytime and nighttime conditions.

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